Storage Stability of Soybean Oil-Based Salad Dressings: Effects of Antioxidants and Hydrogenation

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ABSTRACT

Flavor deterioration of salad dressings was investigated to determine the effect of hydrogenation of the oil, additives and storage conditions. Flavor quality tests were developed and correlated with gas chromatographic analyses of volatile compounds in oils separated from the dressings. Hydrogenation of soybean oil with copper and nickel catalysts effectively increased the storage stability of salad dressings at 21°C but not at 32°C. The use of BHA as an antioxidant in the oil or EDTA as a metal inactivator in the starch base as well as nitrogen packaging were effective in prolonging the storage stability of salad dressings made with unhydrogenated soybean oil. Therefore, these additives or nitrogen packaging may provide economic substitutes for hydrogenation of soybean oil used in salad dressings.

INTRODUCTION

SALAD DRESSINGS containing 30–40% vegetable oil account for 35% of the production of all dressings, mayonnaise and sandwich spreads (Swern, 1982). Potential problems in salad dressing manufacture include: separation, discoloration, off-flavor, oxidative rancidity, loss of consistency, and bacterial and fermentation contamination (Young, 1950). The development of rancidity is an important cause of salad dressing deterioration during marketing (Weiss, 1981). The U.S. Army Natick Research & Development Center reported serious problems with salad dressing procurement specifications to avoid deterioration (Bennett, 1982). Common forms of spoilage in salad dressings and mayonnaise may be due to oxidative degradation of the vegetable oil or egg lipids. Therefore, the starting ingredients must be of good initial quality and have good storage stability (Swern, 1982).

A basic ingredient limitation in salad dressing acceptability has been the quality of the vegetable oil. Soybean oil has a 90% share of the prepared dressings market (American Soybean Association, 1978). Extensive research on soybean oil has resulted in marked improvement in oil stability (Cowan, 1965; Frankel, 1980). Important stability factors include: metal inactivation, protection from air, hydrogenation and winterization. Although several researchers have reported that nitrogen packaging of dressings does extend shelflife (Finberg, 1955; Turney, 1963; McCormick, 1967), the effects of oil hydrogenation and metal inactivation in emulsions have not been well documented. Much research has been directed on methods to stabilize vegetable oil systems including hydrogenation and the use of additives. However, little information is available on the effects of these stabilization techniques in food emulsion systems. Porter (1980) has reported significant differences in the effectiveness of antioxidants depending on their use in pure fats or in emulsion systems.

Commercial salad dressings are presently made with both unhydrogenated and hydrogenated soybean oil. Whether or not hydrogenation is necessary to prepare oxidatively stable salad dressings is a controversial issue in the industry. To resolve important questions on the flavor stability of salad dressing emulsions, this study was aimed at (1) determining the effect of hydrogenation of soybean oil to different linolenic acid contents with copper and nickel catalysts, (2) investigating the effects of additives and storage conditions such as temperature, time and inert gas packaging, and (3) correlating sensory data with volatiles analysis by gas chromatography (GC).

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MATERIALS & METHODS

Salad dressing formulation

A Type II starch-based salad dressing was prepared as outlined in Federal Specification EE-M-131G (1979). The ingredient percentages by weight were: 20% distilled water; 21.5% distilled white vinegar (5% acidity); 14% sucrose; 4% starch blend (Dress'n 300, A.E. Staley Co., Decatur, IL); 0.5% sodium chloride; 5% fresh egg yolk and 35% oil. A starch paste, prepared with the first five ingredients, was cooked to 90°C and cooled to 5°C. The yolks were then added and dispersed well. Oil (1.05 kg) was added at approximately 10 ml/min and emulsified with the starch-egg mixture (3 kg) by a Hobart mixer (Model N-50, Troy, OH) with a paddle attachment. Dressings were also prepared under anaerobic conditions by enclosing the mixer in a small plastic chamber under positive nitrogen pressure during the blending of ingredients. The salad dressings met the Federal Specifications' Type II physical requirements for flavor, color, body, texture and emulsion stability (no phase separation after 56 hr at 38°C).

Oil preparation

A single batch of commercially refined and bleached soybean oil was hydrogenated with copper (Cu) catalyst as described by Moulton et al. (1985). The linolenate content of the oil was reduced from 8.7% to 2.4% in the copper hydrogenated soybean oil (CuHSBO-2.4) and to 0.5% in the copper hydrogenated, winterized soybean oil (CuHWSBO-0.5). A commercial sample of nickel (Ni) hydrogenated soybean oil containing 3.3% linolenate was also used. The Cu hydrogenated soybean oil containing 0.5% linolenate (CuHWSBO-0.5) and the Ni hydrogenated soybean oil (NiHWSBO-3.3) were winterized with resulting yields of 83.5% and 75% respectively (Moulton et al., 1985). All oils had cold test values [American Oil Chemists' Society (AOCS) Procedure Cc 11-53, 1981) of 20 hr or above. The three hydrogenated oils and the refined, bleached soybean oil (SBO) were laboratory deodorized (Mounts et al., 1978). Triglycerides were transesterified with $NaOCH_3$ in methanol and the resulting methyl esters were analyzed by gas-liquid chromatography (GLC) on an EGSS-X packed column (Applied Science, State College, PA). Iodine values were calculated on the basis of GLC analyses. The % *trans* was determined by infrared spectrophotometry at 10.3 μm using methyl elaidate as standard according to the AOCS procedure Cd 14-61 (1981). Fatty acid composition and other analyses of the oils are summarized in Table 1.

Additives

All oils were stabilized with 100 ppm citric acid (J.T. Baker Chemical Co., Phillipsburg, NJ), which was added as a 20% aqueous solution on the cooling side of deodorization. Butylated hydroxyanisole (BHA) (Eastman Chemical Products, Inc., Kingsport, TN) was added to a portion of each oil (200 ppm) as a 10% ethanolic solution, also on the cooling side of deodorization. Calcium disodium ethylenediaminetetraacetate (EDTA) (Dow Chemical Co., Midland, MI) was added as a chelatiing agent to a portion of the starch paste (75 ppm).

Table 1—Analyses of soybean oil (SBO), hydrogenated soybean oils (HSBO), and hydrogenated-winterized soybean oils (HWSBO)

Fatty acid analyses	SBO 8.7% Ln[a]	CuHSBO 2.4% Ln	CuHWSBO 0.5% Ln	NiHWSBO 3.3% Ln
C16:0, %	10.1	10.3	9.5	10.1
C18:0	4.3	4.2	4.0	3.8
C18:1	22.7	30.4	41.9	44.6
C18:2	54.2	52.7	44.1	38.2
C18:3	8.7	2.4	0.5	3.3
trans, %	---	8.4	19.4	16.0
Iodine value	136	124	114	113
Cold test, hr	---	> 36	24	20
Winterization yield, %	---	---	83.5	75

[a] Ln = linolenate

Packaging/Storage

The dressings were packaged in 8 oz wide-mouth clear glass bottles with screw-top closures leaving 2 oz of headspace. All samples were stored in duplicate. The dressings made with SBO and with the three hydrogenated soybean oils were prepared and packaged in an air atmosphere. Additional dressings were also prepared with SBO and with NiHWSBO-3.3 in a nitrogen atmosphere. The bottles for these samples were filled and sealed under a constant stream of nitrogen. The dressings were stored for 2 months at 32°C and for 3 and 6 months at 21°C. Controls used in each sensory test were prepared with soybean oil containing citric acid and packaged with air in the headspace and held at 5°C for the length of each storage period.

Sensory evaluations

A 26-member panel, experienced in analytical-descriptive methods (IFT Sensory Evaluation Div., 1981) was trained to differentiate between salad dressing samples of varying flavor qualities and to provide a descriptive analysis of "off" flavor characteristics. Training samples included fresh and aged dressings made with fresh and oxidized soybean oil, hydrogenated soybean oil and cottonseed oil to represent the range of flavor quality and variety of flavor characteristics in dressings. A majority of the panelists were experienced in evaluating flavor quality of vegetable oils. Environmental conditions of the sensory evaluation facility were previously described by Mounts and Warner (1980). The sensory scaling procedure consisted of an unstructured horizontal line with verbal anchors to define the intensity of each flavor characteristic and the overall flavor quality (Eggert, 1982). Numbers on a 1-10 scale were assigned to each point represented on the line with 1 = weak and 10 = strong for the intensity scale for individual flavor characteristics and 1 = bad and 10 = excellent for the overall flavor quality scale. Descriptions of tastes and flavors listed on the scoresheet included: sweet, sour, grassy, rancid, painty, hydrogenated, stale and unidentifiable. These flavor characteristics were selected by the panelists during preliminary sensory tests. Overall flavor quality encompassed all of the perceptible flavor characteristics, which included sweet and sour tastes for each dressing plus any "off" flavors. As the intensity of the "off" flavors increased, the scores for overall flavor quality decreased.

At each testing session, panelists received 5g each of a control dressing, and two aged dressings. All samples were served at 25°C in uncovered paper cups. The control dressing was prepared with soybean oil containing citric acid and held at 5°C (air in headspace) until each evaluation. Preliminary test results showed that the control dressing was consistently rated as good quality. During actual testing, the control was identified as a good quality product but no specific score or point on the scale was indicated. Panelists were instructed to stir the dressing sample as they evaluated the odor of the control first, followed by the experimental samples in the order received. Panelists then tasted the control and rated it for overall quality and individual description intensity. The two experimental samples were evaluated for flavor in the order of the weakest to the strongest in odor. Panelists rinsed their mouths before and between samples with carbon-filtered tap water heated to 38°C.

Instrumental and chemical analyses

To evaluate the dressings for volatiles and peroxide development a procedure was developed to separate the oils from the salad dressings without the use of organic solvents. This separation was achieved by freezing 100g samples at −4°C for 48 hr. The samples were then warmed to 25°C, centrifuged at 9400 × *g* for 15 min and the separated oil was filtered through a 0.5 in. layer of $MgSO_4$ to remove water, and through a layer of $CaCO_3$ to remove acetic acid.

The oil was analyzed for volatile compounds with a Hewlett-Packard 5700 A gas chromatograph (Palo Alto, CA) fitted with a purge-and-trap attachment (Model 7675A). A 1g oil sample was heated to 60°C with the following purge-and-trap settings: 1 min prepurge, 2 min purge, 8 min desorb, 20 mL/min flow and 250°C desorb. The eluted volatiles were trapped on Tenax-GC (Applied Science, Warrenville, IL) and then desorbed and separated on a stainless steel column (6 ft × 1/8 in) packed with Tenax-GC coated with 7% polymetaphenoxylene (Applied Science, Warrenville, IL). The chromatograph was programmed from 70° to 250°C at 8°C/min with injector temperature of 190°C and detector temperature of 250°C. Peaks were identified by matching retention times with those of reference compounds. Peak areas were integrated electronically. Peroxide values (me/kg) were determined on the separated oil according to the standard AOCS procedure Cd 8-53 (1981).

Microbiological analyses

Diluted aged salad dressings were plated on three types of agar specific for yeasts/molds, aerobic bacteria and lactobacillus, respectively: (1) yeast-malt agar containing tetracycline-HCl; (2) plate count agar (PCA) (Becton, Dickinson and Co., Cockeysville, MD) containing cycloheximide; and (3) Rogosa SL agar (Difco, Detroit, MI) (Kurtzman et al., 1971; Kurtzman and Smittle, 1984). The plated dressings were also examined microscopically for dead cells to determine whether or not viable organisms were present at one time in the samples.

Statistical analyses

A multifactorial design was developed to evaluate the effects of the following four parameters: linolenate at four levels in the oil; three antioxidants/metal chelators; two storage atmospheres and four time-temperature storage periods, for a total of 72 observations. In the first set of dressings, prepared and packaged in air, the effects of four levels of linolenate were compared within each additive treatment group at each storage period. In the second set of dressings, prepared and packaged under nitrogen, the effects of air vs nitrogen atmosphere were compared for two of the linolenate level groups (SBO and NiHWSBO) within each additive group at each storage period. Analysis of variance, linear regression and correlation coefficients were calculated for the sensory data and volatiles analyses (Cochran and Cox, 1957). For sensory data, statistically significant differences in scores were determined by calculating least significant differences (LSD). For GC analyses of volatiles, which showed peak areas ranging widely by integrator counts, a least significant ratio (LSR) was calculated (Snedecor, 1956). All differences indicated as statistically significant were at the 95% confidence level ($P<0.05$).

RESULTS

TO ENSURE that the oils used in these storage stability tests of salad dressings were of good flavor quality, the oil samples were evaluated for flavor and oxidative stability prior to formulation of dressings. All oils received initial scores, indicative of good flavor quality, ranging from 8.4 for the CuHWSBO-0.5 to 7.1 for the NiHWSBO-3.3. Peroxide values for the initial oils were zero. After storage for 8 days at 60°C, the oils ranged in score from 6.6 for the NiHWSBO to 5.1 for the SBO containing BHA compared to 5.3 for the SBO with citric acid only.

The dressings in this study had pH values ranging from 3.3–3.5, which is comparable to commercial dressings that have a pH ranging from 3.2–3.9 (Smittle, 1977). No microbial colonies were detected on the plated samples. Microscopic evaluation of the dressings showed no dead cells present. Therefore, any "off" flavors detected by the panelists were not indicative of microbial spoilage. This observation is in agreement with those of Kurtzman et al. (1971) and Smittle (1977) who reported that microbial growth usually occurs in dressings with a pH range of 3.6–4.1.

Sensory evaluation

To evaluate the aged salad dressings for flavor quality, the panelists were required to note development of "off" flavor characteristics in addition to changes in the intensities of sweet and sour taste. The predominant "off" flavors were stale and

Table 6—Comparisons of total GC volatiles based on calculated ratios between control and experimental salad dressings (data from Table 5)

Sample treatments		Ratios[a] of integrator counts of oils[b] in dressings (Control:Experimental)											
		SBO			CuHWSBO-0.5			CuHSBO-2.4			NiHWSBO-3.3		
Control	Experimental	2 mo 32°C	3 mo 21°C	6 mo 21°C	2 mo 32°C	3 mo 21°C	6 mo 21°C	2 mo 32°C	3 mo 21°C	6 mo 21°C	2 mo 32°C	3 mo 21°C	6 mo 21°C
SBO[c]	Hydrogenated Oil[c]				1.4	1.5	1.5	0.6	2.1	1.7	0.6	1.5	1.4
Citric Acid	BHA	1.4	1.2	2.1	0.6	1.0	1.1	1.5	0.8	1.1	1.5	1.5	1.3
Citric Acid	EDTA	1.9	1.2	2.0	0.9	1.3	1.3	2.6	0.6	3.5	4.5	1.5	2.9
Air	N_2												
+ Citric Acid	+ Citric Acid	6.0	1.2	2.2	---[d]	---	---	---	---	---	3.3	0.7	0.8
+ BHA	+ BHA	2.1	0.9	0.6	---	---	---	---	---	---	16.5	0.2	0.6
+ EDTA	+ EDTA	1.8	1.2	0.9	---	---	---	---	---	---	5.5	0.6	0.2

[a] Least Significant Ratio (LSR) ≥1.2 ($P<0.05$) between control and experimental treatments.
[b] Oil Identification = SBO (Soybean Oil); CuHWSBO-0.5 (Copper hydrogenated, winterized SBO-0.5% linolenate); CuHSBO-2.4 (Copper hydrogenated SBO-2.4% linolenate); NiHWSBO-3.3 (Nickel hydrogenated, winterized SBO-3.3% linolenate)
[c] + Citric Acid; in air
[d] --- not tested

Table 7—Effect of storage in air and nitrogen on pentane[a] plus hexanal[a] and peroxide values in oils isolated from salad dressings

Oil[b]	Additive[c]	Headspace	Pentane + hexanal				Peroxide value (me/kg)			
			Initial	2 mo 32°C	3 mo 21°C	6 mo 21°C	Initial	2 mo 32°C	3 mo 21°C	6 mo 21°C
SBO										
	None	Air	4	14	24	63	1	18	15	20
	BHA	Air	21	12	20	32	1	8	6	31
	EDTA	Air	2	10	20	56	---[d]	9	4	12
SBO										
	None	N_2	(4)[e]	2	21	32	---	16	12	25
	BHA	N_2	(21)[e]	7	26	69	---	18	22	29
	EDTA	N_2	(2)[e]	6	21	62	---[d]	6	2	11
CuHWSBO-0.5										
	None	Air	1	15	13	47	0	7	17	27
	BHA	Air	23	24	17	44	0	11	18	33
	EDTA	Air	4	21	15	54	0	8	2	12
CuHSBO-2.4										
	None	Air	1	15	12	44	0	15	19	32
	BHA	Air	14	21	16	38	0	11	16	30
	EDTA	Air	13	15	28	24	0	11	8	15
NiHWSBO-3.3										
	None	Air	18	12	29	75	0	11	14	21
	BHA	Air	20	1	33	55	0	5	14	20
	EDTA	Air	6	2	15	99	0	6	4	7
NiHWSBO-3.3										
	None	N_2	(18)[e]	12	29	75	---	5	11	21
	BHA	N_2	(20)[e]	1	33	75	---	10	13	21
	EDTA	N_2	(6)[e]	2	24	99	---	1	1	4

[a] Integration units × 10^4, mean values for duplicate determinations. Least significant ratio (LSR) = 1.2 ($P<0.05$). Relative standard deviation = ±7.7%
[b] Oil identification = SBO (Soybean Oil); CuHWSBO-0.5 (Copper hydrogenated, winterized SBO-0.5% linolenate); CuHSBO-2.4 (Copper hydrogenated SBO-2.4% linolenate); NiHWSBO-3.3 (Nickel hydrogenated, winterized SBO-3.3% linolenate)
[c] All oils contain citric acid
[d] --- not tested
[e] Assumed same as in air

the effect of EDTA were for a dressing made with CuHWSBO-0.5 and aged 2 months at 32°C (LSR = 0.9) and for a sample prepared with CuHSBO-2.4 and stored 3 months at 21°C (LSR = 0.6). Correlation coefficients between flavor scores and total volatile compounds in dressings with EDTA were: −0.36, after the 2-months storage at 32°C; −0.78, after 3 months storage at 21°C, and −0.75 after the 6-months storage at 21°C. Therefore, volatiles analysis of the oils isolated from the dressings aged 3 and 6 months at 21°C was the most sensitive monitor of the effect of EDTA on quality. The use of BHA significantly decreased volatile formation in dressings prepared with either SBO or NiHWSBO-3.3 (LSR range 1.2-1.5) (Tables 5 and 6) compared to dressings containing citric acid only. However, BHA was no more effective than citric acid in dressings prepared with CuHWSBO-0.5 or CuHSBO-2.4. Only at the more severe storage of 2 months, 32°C did BHA prevent more volatiles formation in CuHSBO-2.4 (LSR = 1.5) than did citric acid.

Nitrogen had a significant effect in decreasing volatile formation in dressings prepared with SBO compared to similar samples prepared in air. In the samples containing citric acid only, the LSR values ranged from 1.2 to 6.0 for the three storage periods (Table 6). The use of nitrogen prevented significant volatile formation in dressings made with SBO and BHA only after storage of 2 months (LSR = 2.1); whereas the effect was significant for dressings made with SBO and EDTA at both the 2 month and 3 month storage periods. Nitrogen also significantly decreased volatiles in dressings prepared with NiHWSBO-3.3 and aged at 2 months (LSR values 3.3–16.5). However, more volatiles were formed in dressings prepared with NiHWSBO-3.3 in a nitrogen atmosphere than in air after storage at 3 and 6 months. These results are consistent with the negative effect of nitrogen atmosphere observed with flavor quality scores (Table 4).

Aged dressings containing BHA or EDTA and packaged under nitrogen had some extraneous, unidentified peaks in the gas chromatograms. To determine whether or not these peaks affected analyses of total volatiles, peak areas for pentane and hexanal were added separately (Table 7). These results showed similar trends as those based on total volatiles (Table 5). With salad dressings made with SBO, storage under nitrogen decreased the combined total peak area of pentane and hexanal. However, in the presence of additives, storage under nitrogen showed either no effect or an actual increase in pentane and

Table 3—Flavor characteristics of aged salad dressings

Oil[a]	Additive	Headspace	Flavor characteristics[b,c]											
			Sweet			Sour			Stale			Rancid		
			2 mo 32°C	3 mo 21°C	6 mo 21°C	2 mo 32°C	3 mo 21°C	6 mo 21°C	2 mo 32°C	3 mo 21°C	6 mo 21°C	2 mo 32°C	3 mo 21°C	6 mo 21°C
SBO	None	Air	5.6	5.5	5.1	6.3	6.5	6.0	2.2	1.0	1.0	1.9	1.5	0.3
	BHA	Air	5.6	5.4	5.9	6.5	6.7	6.5	1.7	0.4	0.3	0.6	0	0.5
	EDTA	Air	5.7	4.9	5.9	6.4	6.5	6.5	0.7	0.9	0.5	0.4	0	0
SBO	None	N_2	5.2	5.5	5.7	6.7	6.9	6.4	1.5	1.0	0.8	0	0	0
	BHA	N_2	5.7	5.3	5.5	6.9	6.6	6.8	1.2	1.1	0.8	0.7	0.7	0
	EDTA	N_2	5.5	5.5	5.1	7.1	6.7	6.2	1.3	0.6	0.6	0.4	0	0.5
CuHWSBO-0.5	None	Air	5.5	5.6	5.7	6.3	7.2	6.5	1.7	1.3	1.2	0.7	0	0.2
	BHA	Air	5.2	5.5	6.0	5.9	6.7	6.8	1.1	0.6	1.2	0.6	0	0.4
	EDTA	Air	6.0	5.9	5.6	7.0	6.8	6.6	1.4	1.0	0.8	0.2	0	0
CuHSBO-2.4	None	Air	5.7	5.6	5.6	6.9	6.4	6.4	2.2	1.1	0.7	1.4	0.4	0
	BHA	Air	4.6	5.4	5.8	6.3	6.8	6.2	1.5	0.8	0.7	1.1	0	0
	EDTA	Air	6.3	5.1	6.5	6.4	6.5	7.0	1.7	0.4	0.5	0.3	0	0
NiHWSBO-3.3	None	Air	5.5	5.6	5.5	6.3	6.8	6.5	1.1	1.6	0.8	0.6	0.5	0
	BHA	Air	6.1	5.5	6.1	6.9	7.0	6.9	1.1	0.6	0.7	0.9	0	0
	EDTA	Air	5.4	5.9	5.7	7.0	6.7	6.2	1.0	0.6	0.3	0	0	0
NiHWSBO-3.3	None	N_2	6.2	5.5	5.6	7.2	7.0	6.6	1.5	0.8	1.1	0	0.3	0.7
	BHA	N_2	5.9	5.1	5.7	7.1	6.7	7.1	1.4	0.7	0.6	0.2	0.2	0
	EDTA	N_2	5.6	5.9	4.8	6.9	6.6	6.3	1.8	0.6	0.9	0.4	0	0.9

[a] Oil identification = SBO (Soybean Oil); CuHWSBO-0.5 (Copper hydrogenated, winterized SBO-0.5% linolenate); CuHSBO-2.4 (Copper hydrogenated SBO-2.4% linolenate); NiHWSBO-3.3 (Nickel hydrogenated, winterized SBO-3.3% linolenate)
[b] SBO Control = 6.1, sweet; 7.1, sour; no "off" flavors
[c] Least significant difference (LSD) = 1.0

Table 4—Effects of storage in air or nitrogen on flavor quality scores[a] of salad dressings

Oil[b]	Additive[c]	Headspace	Storage time/temperature			
			Initial	2 mo 32°C	3 mo 21°C	6 mo 21°C
SBO						
	None	Air	8.0	5.5	5.6	6.6
		N_2		6.2	6.8	6.7
	BHA	Air	8.0	5.3	7.3	6.5
	BHA	N_2		6.0	6.4	7.0
	EDTA	Air	7.8	6.6	6.7	6.9
	EDTA	N_2		6.2	6.3	6.5
NiHWSBO-3.3						
	None	Air	7.8	5.6	6.4	6.7
		N_2		6.6	5.9	6.5
	BHA	Air	7.7	6.0	7.1	7.0
	BHA	N_2		6.7	6.3	6.9
	EDTA	Air	8.0	6.7	7.3	7.0
	EDTA	N_2		6.1	7.1	6.1

[a] Least significant difference (LSD) = 0.7
[b] Oil identification = SBO (Soybean Oil); NiHWSBO-3.3 (Nickel hydrogenated, winterized SBO-3.3% linolenate)
[c] All oils contain 100 ppm citric acid

Table 5—Effect of storage in air and nitrogen on total GC volatiles[a] in oils isolated from salad dressings

Oil[b]	Additive[c]	Headspace	Storage time/temperature			
			Initial	2 mo 32°C	3 mo 21°C	6 mo 21°C
SBO						
	None	Air	10	30	42	138
		N_2	(10)[d]	5	35	64
	BHA	Air	26	21	37	67
		N_2	(26)[d]	10	41	119
	EDTA	Air	2	16	36	69
		N_2	(2)[d]	9	31	78
CuHWSBO-0.5						
	None	Air	3	22	27	94
	BHA	Air	36	35	26	85
	EDTA	Air	7	26	21	75
CuHSBO-2.4						
	None	Air	5	47	20	81
	BHA	Air	20	31	25	71
	EDTA	Air	21	18	36	23
NiHWSBO-3.3						
	None	Air	28	50	28	97
		N_2	(28)[d]	15	38	126
	BHA	Air	25	33	15	74
		N_2	(25)[d]	2	61	121
	EDTA	Air	12	11	19	34
		N_2	(12)[d]	2	34	163

[a] Integration units × 10^4, mean values for duplicate determinations. Least significant ratio (LSR) = 1.2 ($P<0.05$). Relative standard deviation = ±7.7%.
[b] Oil identification = SBO (Soybean Oil); CuHWSBO-0.5 (Copper hydrogenated, winterized SBO-0.5% linolenate); CuHSBO-2.4 (Copper hydrogenated SBO-2.4% linolenate); NiHWSBO-3.3 (Nickel hydrogenated, winterized SBO-3.3% linolenate)
[c] All oils contain 100 ppm citric acid
[d] Assumed same as in air

(≥1.2) indicated a significant effect of experimental treatments in decreasing total volatiles relative to control samples (Table 6).

After storage at 21°C for 3 and 6 months, dressing prepared with hydrogenated oils formed significantly less total volatile compounds than dressings made with unhydrogenated oil (Table 5). The LSR values ranged from 1.4 to 2.1 for comparisons between aged dressings made with SBO (Control) and with NiHWSBO-3.3 aged 6 months (LSR = 1.4) or CuHSBO-2.4 aged 3 months (LSR = 2.1) (Table 6). However, this stabilizing effect of hydrogenation was only observed after 2 months storage in the dressing made with CuHWSBO-0.5 (LSR = 1.4). These results follow the same trend as the flavor quality evaluations of dressings aged 2 months at 32°C and 3 months at 21°C (Table 2). Linear regression analysis of flavor quality scores and total volatiles in the samples containing citric acid only showed correlation coefficients of −0.20, −0.70, and −0.54 for dressings aged in air 2 months at 32°C, 3 months at 21°C and 6 months at 21°C, respectively. Therefore, as in flavor evaluation results, storage for 3 months was the most sensitive condition to show the effect of hydrogenation on the stability of these dressings based on total volatile analyses.

The use of EDTA significantly decreased the amount of volatiles in most dressings compared with control samples containing citric acid only (Tables 5 and 6). Two exceptions in

Table 2—Effects of hydrogenation, additives, and storage in air on overall flavor quality scores[a] of salad dressings

Oil[b]	Additive[c]	Storage time/temperature: Initial	2 mo 32°C	3 mo 21°C	6 mo 21°C
SBO					
	None	8.0	5.7	5.6	6.6
	BHA	8.0	5.5	7.3	6.5
	EDTA	7.8	6.6	6.7	6.9
CuHWSBO-0.5					
	None	7.7	5.1	6.8	6.5
	BHA	7.7	6.0	6.6	6.0
	EDTA	8.1	6.6	6.4	6.6
CuHSBO-2.4					
	None	7.8	5.6	6.5	7.2
	BHA	8.0	5.5	7.2	6.6
	EDTA	7.9	6.1	6.4	7.1
NiHWSBO-3.3					
	None	7.8	5.6	6.4	6.7
	BHA	7.7	6.4	7.1	7.0
	EDTA	8.0	6.7	7.3	7.0

[a] Least significant difference (LSD) = 0.7

[b] Oil identification = SBO (Soybean Oil); CuHWSBO-0.5 (Copper hydrogenated, winterized SBO-0.5% linolenate); CuHSBO-2.4 (Copper hydrogenated SBO-2.4% linolenate); NiHWSBO-3.3 (Nickel hydrogenated, winterized SBO-3.3% linolenate)

[c] All oils contain 100 ppm citric acid

rancid, but descriptions such as grassy, hydrogenated and painty were also used occasionally.

Effect of hydrogenation. Flavor quality scores were compared on the dressings prepared with the four oils containing only citric acid and processed in air. Initial quality of the dressings showed no significant effect of hydrogenation (Table 2). Scores ranged from 7.7–8.1 for all samples compared to 8.0 for the control dressing (LSD = 0.7). The dressings were described as slightly more sour than sweet with an average sour taste intensity of 7.1 and an average sweet taste intensity of 6.1. Few "off" flavors were reported.

After storing dressings in air for 2 months at 32°C and for 3 and 6 months at 21°C the flavor quality scores were all significantly decreased relative to the control dressing (Table 2). Scores ranged from 5.1–6.7 for dressings after 2 months at 32°C; from 5.6–7.3 after 3 months at 21°C and from 6.0–7.2 after 6 months at 21°C, indicating poor to good quality. Taste intensities for sweet and sour generally decreased in the salad dressings with increasing storage time (Table 3). The decreases may be attributed to a mellowing or blending of these two tastes as well as to the development of "off" flavors which could mask the sweetness and sourness. After the 3-month storage, dressings made with hydrogenated oils had significantly higher quality scores than the sample prepared with unhydrogenated oil because of the significantly higher intensity of rancid flavor in the dressing made with unhydrogenated oil. No significant differences in scores were noted among the three hydrogenated oils. After 6 months of storage at 21°C and 2 months at 32°C, dressings prepared with hydrogenated oils were rated as not significantly different than the dressings made with unhydrogenated oil. Dressings aged for 2 months had the highest stale and rancid flavor intensities.

Effect of additives. Flavor quality scores were compared on dressings prepared with the same oil type but with different additives. Quality scores of the dressings aged for 2 or 3 months were significantly improved in most samples containing BHA or EDTA compared with dressings containing only citric acid (Table 2). The most pronounced effect of EDTA was noted after 2 months storage at 32°C. The use of EDTA prevented significant deterioration in dressings made with SBO, CuHWSBO-0.5 and NiHWSBO-3.3. After 3 months of storage at 21°C, dressings made with SBO and EDTA and with NiHWSBO-3.3 and EDTA were rated significantly higher in quality than samples made with these oils containing only citric acid. After 2 months of storage at 32°C, the dressing prepared with SBO and EDTA had a significantly higher flavor quality score than all dressings made with hydrogenated oils and citric acid only. Therefore, EDTA was more effective than hydrogenation in preventing flavor deterioration under this severe storage condition. However, after 3 months of storage at 21°C, EDTA was as effective as hydrogenation in protecting dressing quality. Compared with citric acid only, the use of BHA improved the flavor quality of several dressings including those made with: NiHWSBO-3.3 and CuHWSBO-0.5 after storage for 2 months at 32°C and SBO, NiHWSBO-3.3 and CuHSBO-2.4 after 3 months at 21°C. After 6 months storage at 21°C, dressings prepared with either EDTA or BHA showed no significant differences from dressings prepared with oils treated with citric acid only. No synergistic effect of hydrogenation and additives occurred at any of the storage conditions in air. The use of EDTA decreased the intensities of stale and rancid flavors in salad dressings aged in air at the three storage times (Table 3). However, statistically significant differences were observed in only a few comparisons. Dressing prepared with SBO and with EDTA and aged 2 months at 32°C not only had significantly lower intensities of stale and rancid flavors than the dressing made with CuHSBO-2.4 containing only citric acid, but also a lower intensity of stale flavor than the sample prepared with CuHWSBO-0.5. The use of BHA caused significant decreases in "off" flavor intensities in dressings prepared with either NiHWSBO-3.3 or SBO, containing only citric acid and aged in air for 3 months at 21°C. Although the use of EDTA was more effective than hydrogenation in preventing deterioration in dressings aged 2 months, both methods enhanced the stability of the dressings aged at 3 months.

Effect of nitrogen atmosphere. Flavor quality scores were compared on dressings prepared and packaged in an air atmosphere vs. dressings made with the same oil type and additives under a nitrogen atmosphere. Dressings made with SBO received higher flavor quality scores after 2 and 3 months of storage under nitrogen than dressings processed and stored in air (Table 4). This result was probably due to significant differences in rancid flavor intensities (Table 3). Under nitrogen atmosphere, dressings made with either SBO or NiHWSBO-3.3 oil plus BHA had significantly higher flavor scores than similar samples processed and aged in air. In several stabilized samples, a nitrogen atmosphere resulted in lower scores than for corresponding dressings processed in air. Dressings containing EDTA and aged for 2 months at 32°C under nitrogen were rated lower than equivalent samples aged in air. All samples aged for 3 months at 21°C under nitrogen were rated lower than the same dressings processed in air except for the dressing made with SBO and citric acid only. No significant differences between air and nitrogen packaging were noted for the dressings aged 6 months at 21°C. Therefore, preparation and storage of salad dressings under nitrogen were of benefit when NiHWSBO and SBO were used alone or with BHA after 2 months storage. Nitrogen atmosphere was also of benefit in dressings made with SBO containing only citric acid and aged 3 months.

Analysis of volatiles by gas chromatography

The gas chromatogram of volatile compounds, obtained with a purge-and-trap technique using a packed column, showed 12 peaks consistently appearing in oils separated from the salad dressings. Major volatile compounds included pentane and hexanal (Tables 5-7). Minor volatiles were pentanal, heptanal and 2,4-decadienal. In previous work (Fore et al., 1978; Legendre et al., 1980; Min and Tickner, 1982) done by the direct injection technique, the same volatiles were also reported in salad dressings but larger amounts of 2,4-decadienal were observed. Previous work by Snyder and Frankel (1985) on volatile analyses of oils by a static headspace technique showed that low-boiling compounds such as pentane and hexanal were detected in much larger amounts than high-boiling compounds such as 2,4-decadienal. Least significant ratios (LSR) were calculated to facilitate comparisons ($P<0.05$) between integrator counts of total volatiles listed in Table 5. High LSR values

hexanal. Correlation coefficients between flavor scores and hexanal contents were comparable to the coefficients calculated between scores and total volatiles. On the other hand, correlation coefficients between scores and pentane were not significant.

Peroxide values

Peroxide value determinations in oils isolated from dressings varied initially from 0–1 for the hydrogenated and unhydrogenated oils (Table 7). Hydrogenation was only effective in decreasing peroxide values after 2 months of storage at 32°C. Little difference was observed between the dressings with unhydrogenated oil and those with hydrogenated oils after 3 and 6 months of storage. These results were observed for samples packaged in either air or nitrogen. The effect of hydrogenation in lowering peroxide values after the 2-month storage is in contrast to the flavor evaluations (Table 2) and total volatile analyses (Table 5), which show no effect from hydrogenation. Therefore, we found no relation between peroxide values of dressings made with hydrogenated and nonhydrogenated oils and results based upon flavor and volatile analyses.

The use of EDTA was effective in lowering peroxide values in all four oil types and at all storage times and temperatures with dressings prepared and packaged in air (Table 7). On the other hand, BHA had a limited effect with only dressings made with SBO and aged either 2 months at 32°C or 3 months at 21°C and in dressing made with NiHWSBO-3.3 and aged 2 months at 32°C. We found EDTA prevented increases in peroxide values more effectively than either hydrogenation or BHA.

In the presence of BHA, dressings packaged under nitrogen had higher peroxide values than similar samples packaged in air. In the presence of citric acid only or EDTA, peroxide values were generally lower for those dressings packaged under nitrogen than in air. The use of nitrogen packaging was equally effective in SBO and in the NiHWSBO-3.3 when dressings contained either EDTA or citric acid.

DISCUSSION

SALAD DRESSINGS are multiphase emulsion systems that undergo complex interactions on storage in air. Therefore, simple, straightforward correlations may not be expected between sensory analyses and chemical or instrumental tests such as peroxide values and gas chromatographic volatile analyses. Mounts et al., (1978, 1981) reported that hydrogenation did not improve the flavor stability of soybean oil either in the presence or absence of BHA. However, oxidative stability measured by peroxide values was improved with either hydrogenation or BHA. The lack of effectiveness in the flavor stability of oils by hydrogenation and BHA (Mounts et al., 1978) is in contrast to this present study with salad dressing emulsions showing a positive effect from hydrogenation and/or BHA. However, our results with dressings are consistent with previous reports that BHA is more active in stabilizing emulsion systems than bulk vegetable oil systems (Porter, 1980). According to this theory, since BHA is very lipophilic, it would be more effective in emulsions because more of the antioxidant is located close to the boundary layer in the lipid miscelles, where oxidation is most intense.

This study showed that hydrogenation of soybean oil effectively increased the storage stability of salad dressings at 21°C but not at 32°C. The use of BHA as an antioxidant in the oil or EDTA as a metal inactivator in the starch base as well as nitrogen packaging were effective in prolonging the storage stability of salad dressings made with unhydrogenated soybean oil. No synergistic effect was noted from hydrogenation combined with additives or nitrogen packaging. Therefore, the use of antioxidants, EDTA, or nitrogen packaging may provide economic substitutes for hydrogenation of soybean oil used in salad dressings.

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Ms received 9/13/85; revised 12/26/85; accepted 1/2/86.

Research was carried out under contract with the U.S. Army Natick Research & Development Center, Natick, MA 01760. The authors acknowledge L. Parrott, J. Aspin, A. Patterson, R. Holloway, D. Brooks, for technical assistance; W. Kwolek, W. Bailey for statistical analyses; and C. Kurtzman for microbiological evaluations.

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